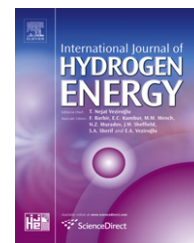


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Technical Communication

Dish Stirling technology: A 100 MW solar power plant using hydrogen for Algeria

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ABSTRACT

In Algeria, the electricity demand is rapidly increasing. At the same time, Algeria is very rich in solar energy resources and possesses large wasteland areas in the Sahara that represent 80% of the total area and the market of solar energy is very promising. All these indicators make Algeria an ideal country for the implementation of the Concentrating Solar Thermal Power Plant technologies (CSTPP). In order to study whether the implementation of CSTPP under Algerian climate is economically feasible, we present in this article a techno economic assessment of 100 MW of CSTPP based on Dish Stirling technology using hydrogen as working fluid for centralized electricity production located in three typical sites of each geographical regions of Algeria (Algiers, In Salah and Tamanrasset). The National Renewable Energy Laboratory's SAM software (Solar Advisor Model) is used to evaluate the monthly energy production, annual energy output and the Levelized cost of energy (LCOE) for this study. The results indicate that Tamanrasset is the suitable site yielding the lower LCOE (11.5 c\$/kWh) and the higher annual net electric energy output (221 GWh/y).

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1. Introduction

Presently, all countries of the world depend on fossil fuels for their energy needs. The hydrocarbons are the dominant energy source; they cover about 80% of the world's needs [1]. The electricity generated by the conventional fossil technology in some countries has a low cost with a high availability. The use of these technologies should be reduced in future due to their limited sources, increasing prices and environmental impact. On the other hand, the obligation to reduce CO₂ and other gaseous emissions is the reason behind which countries turn to non polluting renewable energy sources, such as solar energy.

With respect to Algeria, the population has almost doubled in the last 25 years from 19 million in 1980 to 34 million in 2008 [2]. The population growth has a direct impact on energy requirements. For this, Algeria's electricity demand is growing rapidly during recent years (5–7% per year). SONEGAS (Electricity and Gas National Enterprise) that is the sole, state owned electricity generation, transmission and distribution utility, has around 8926 MW of installed power generating capacity since it was established in 1969 to the end of 2008 [3]. Out of this 50% is generating by gas turbine unit, 45% by steam unit and 2% is generated by hydraulic option while 1.96% is generated by diesel generators. This option is used

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particularly in the rural areas in the Sahara with no connection to the power grid, although these devices have undesirable environmental effects.

The level of consumption of energy is indicative of the level of quality of life of a country [4]. The number of electricity consumers in Algeria has increased from 4,389,000 in 2000 to 6,275,000 in 2008. In the other hand, the electricity growth has reached 40,267 GWh in 2008 from 25,412 GWh in 2000. This situation is due mainly to rapid growth in residential, commercial and industrial sectors.

The installed power generating capacity has not been sufficient to reach demand during peak cooling periods in the summer. For this, the Algerian power sector will need to grow over the next years in order to satisfy the power demand. The new power plants should be environmentally.

Currently, Algeria envisages the substitution of the fossil energies by the renewable energy. In this context, the government of Algeria has committed itself to develop solar energy as its largest renewable energy source; to cover 5% of the national electricity needs by 2012 with renewable energy [5]. Ambitious national programmes have been established in the last years [6]; in 2000 a programme of rural electrification of 20 villages in the Sahara has been launched [7]. In 2005, the agency New Energy Algeria (NEAL) launched an invitation to build the Algeria's first large solar thermal power plant [8]. It is a hybrid 130 MW integrated solar combined cycle system (ISCCS) with 30 MW of solar output [9]. It will be the first among four hybrid power stations projects [10] with the aim to take advantage of the ideal opportunities combining Algeria's richest natural gas with Algeria's most abundant solar energy source.

In the framework of our research project, we try to contribute in other type of CSTPP; the Dish Stirling technology. Taking into account its high efficiency, important degree of reliability and its cost which has considerably decreased during the last years.

In this feasibility study, a preliminary attempt toward the technical and economical assessment of dish Stirling technology using hydrogen as working fluid for centralized electricity production has been made. In the present research, a plant of 100 MW has been taken as reference case in order to value whether the implementation of this technology in three typical sites of each climatic regions of Algeria is economically feasible. Analysis of energy yield and economic feasibility of the plant proposed have been carried out using National Renewable Energy Laboratory's (NREL) SAM software [11]. SAM provides modeling capability for several technologies including the Dish Stirling technology.

The paper is set out as follow. Section 2 provides a brief description of Dish Stirling technology. In section 3 the solar potential of Algeria is presented while section 4 presents the simulation study, including the dish Stirling power plant characteristics considered in this study, the energy output and the economic assessment of the plant. In section 5, the results are discussed in detail and the last section is reserved to summarize the conclusions.

2. Dish Stirling technology

The Dish Stirling systems shown in Fig. 1 use mirrored dishes to focus and concentrate sunlight onto a solar receiver located

at the focal point of the dish. The receiver is designed to transfer the absorbed solar energy to the working fluid (hydrogen in the most cases) in Stirling engine. The Stirling engine then converts the absorbed thermal energy to a mechanical power by compressing the working fluid when it is cool and expanding it when it is hot. The linear motion is converted to a rotary motion to turn a generator to produce electricity, as shown in Fig. 2. To increase the efficiency of these systems; they must be equipped with a dual tracking solar mechanism that keeps the dish aperture always normal to the incoming solar radiation.

The Dish Stirling systems have demonstrated the highest efficiency of any solar power generation system by converting nearly 31.25% [12] of direct normal incident solar radiation into electricity after accounting for parasitic power losses. Therefore The Dish Stirling technology is anticipated to surpass parabolic troughs by producing power at more economical rates and higher efficiencies. Because the Dish Stirling systems are modular; each system is a self-contained power generator, they can be assembled into plants ranging in size from a kilowatts to 10 MW [13]. These systems can also be combined with natural gas and the resulting hybrid provides continuous power generation like other conventional solar energy systems [14]. Dish Stirling systems are applicable in the regions having high level of Direct Normal Irradiance; the so-called Sun Belt area which includes: the northern Africa (where Algeria is located), Mexico, Southwest of USA, Australia, MENA region.

Actually, there are only two Dish Stirling systems, which have been developed to a state close to commercialization: the Euro Dish from Schlaich-Bergermann und Partner (SBP) and the "SunCatcher Dish Stirling system" developed by Stirling Energy Systems (SES). The SunCatcher Dish Stirling systems have a refined design that will be used in commercial scale deployments beginning in 2010 [15].

Solar Dish Stirling technology is one of the oldest solar technologies [16]. There are a wide number of past and current demonstration projects, mostly in Europe, Japan, Australia and in USA [14, 17]. All dish Stirling system installations realized are reported in [18,19].

This technology has reached an important step with the large scale solar dish Stirling systems planned to be constructed

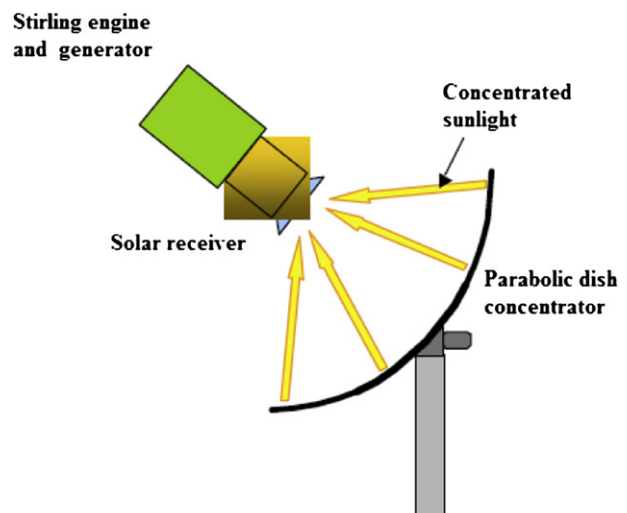


Fig. 1 – Solar dish Stirling System.

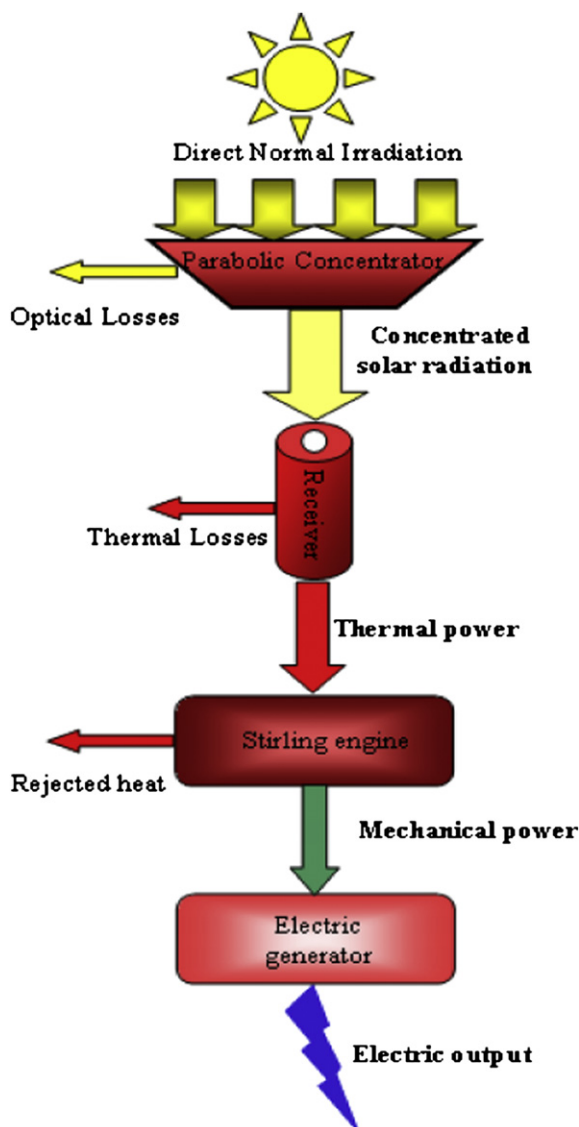


Fig. 2 – Solar dish Stirling System energetic chain.

within the framework of Solar One and Solar Two projects of company Stirling Energy System (SES) launched on 2005[20,21]. Overall, the two projects together will include 64,000 dishes, generating 1750 MW, which will provide electricity for approximately 1,100,000 homes [22]. The two plants are expected to deliver grid quality power by the end of 2010 [23].

2.1. Stirling engine

The Stirling engine is a device, which operates on a closed regenerative thermodynamic cycle, with cyclic compression and expansion of the working fluid at different temperature levels [24]. It can be described as an assembly of pistons and heat exchangers. A typical arrangement has two pistons and three heat exchangers. The pistons, a displacer and a power piston, affect the fluid motion inside the machine, and the heat exchangers affect the heat transfer from the heat addition and heat rejection devices and heat flows internal to the engine. In order to obtain net positive work from the power

piston, the displacer and power pistons are not in phase with each other. This phase difference is manifested in the two major categories of Stirling engines: the kinematic and the free-piston.

- Kinematic design: The phase difference is controlled by a mechanical linkage, such as a crankshaft or a swash-plate, between the displacer and the power piston. At this moment the kinematics Stirling engines, the Kockums (United Stirling) 4–95 25 kWe, Stirling Thermal Motors (STM) 4–120 25 kWe and the SOLO 161 11 kWe are the examples for the engines used for solar dish Stirling systems.
- Free - piston design: There is no direct mechanical linkage between the two pistons; the necessary phase difference is determined by the varying pressures in the cycle and the dynamic response of the components. The free-piston design can result in a hermetic containment with no fluid inventory losses, but the lack of a mechanical linkage between the displacer and the power piston may result in non-optimum performance. These designs promise long lifetimes with minimal maintenance requirements. Actually, no free-piston Stirling engines are being developed for solar dish applications.

2.2. Concentrator

The size of the solar concentrator for Dish Stirling systems is determined by the power output desired at maximum insolation levels (1000 W/m^2) and the collector and power conversion efficiencies. With current technologies, a 5 kWe Dish Stirling system requires a dish of 5.5 m, in diameter. 10 kWe requires a dish of 7.5 m in diameter and a 25 kWe system requires a dish of 10 m in diameter. Because of the parabolic shape, the dishes have concentrations ratios ranging from 600 to 2000 and they can achieve temperatures in excess of 1500°C [25]. The world's largest concentrator is the "big Dish" in Australia which has an aperture of 500 m^2 . The Big Dish has 380 identical spherical $1.17 \text{ m} \times 1.17 \text{ m}$ mirror panels, which incorporate the Glass-on-Metal Laminate mirrors. The construction of a first prototype on the Australian National United (ANU) campus began in the first quarter of 2008. The first on sun test was carried out on 29 June 2009 [26]. The ideal concentrator has a parabolic shape. Some solar collectors approximate this form using the technologies cited below [27]:

- Glass-faceted concentrators: Use spherically curved individually alignable glass mirror facets, mounted on an approximate parabolic-shaped structure. These designs generally have high concentration ratios and they also tend to be heavy and expensive and require accurate alignment of a large number of mirrors.
- Full-surface parabolic concentrators: The entire surface forms an approximately parabolic shape.
- Stretched-membrane concentrators: It can be a single-facet or multifaceted. The design incorporating thin membranes stretched over both sides of a metal ring. The membranes may be thin plastic sheeting or thin metal sheeting with a reflective coating applied to one of the membranes. This technology revealed problems of behavior of materials. Nowadays, it is reserved for parabolas of smaller diameter.

Table 1 – Regional daily solar energy and sunshine duration in Algeria.

Region	Coaster line	High plateaux	Sahara
Area (km ²)	95,271	238,174	2,048,296
Mean daily sunshine duration (h)	7.26	8.22	9.59
Solar daily energy density (kWh/m ²)	4.66	5.21	7.26
Potential daily energy (10 ¹² Wh)	443.96	1240.89	14,870.63

Concerning the reflective surface, three types are used in concentrator designs

- Reflective surface of aluminum or silver deposited on glass or plastic; it's the most durable reflective surfaces with a reflectance value in the range of 95%. This concept is used in many current concentrator designs (Suncatcher systems, EURODISH, WGA, big dish).
- Reflective polymer films; they have the low cost but their optical and mechanical properties get damaged after long exposure to ultraviolet rays. They are characterized by low cost, flexibility and high reflectance (96%).
- Reflected polished aluminum sheet; they have a low cost. Their major disadvantages are that they have only a moderate specular reflectance (85%) and a poor weatherability.

2.3. Receiver

Receivers for dish Stirling systems are cavity receivers with a small aperture through which concentrated sunlight enters. The receiver aperture is optimized to be just large enough to admit most of the concentrated sunlight but small enough to limit radiation and convection loss. Two different heat

Table 2 – Design characteristics and performances of 25 kW Dish Stirling System.

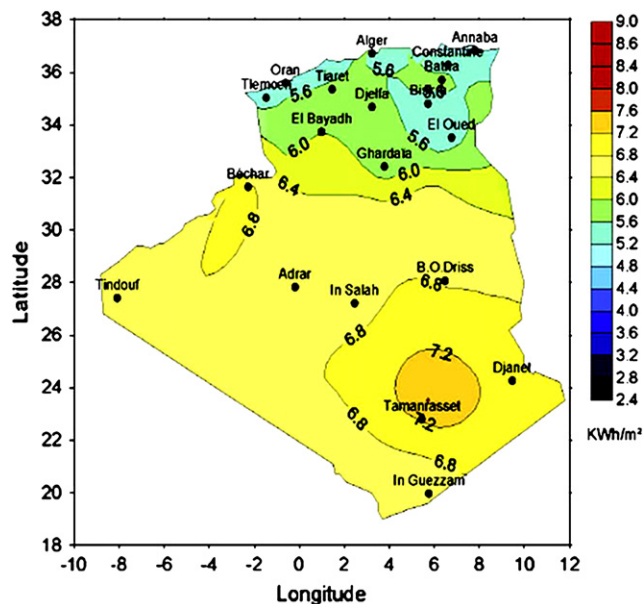
Specifications	Quantity
Concentrator	
Type (and N° of facets)	Faceted (82)
Reflecting area	Thin glass mirror
Diameter	10.57 m
Projected area	87.7 m ²
Glass area	91.01 m ²
Reflectivity	0.91
Concentration factor	7500
Focal length	7.45 m
Optical efficiency	0.88
Receiver	
Aperture diameter	0.2 m
Receiver temperature	720 °C
Working pressure	20 Mpa
Receiver efficiency	0.9
Stirling engine (kinematics)	
Type	Kockums 4–95 SES
Size	4 cylinders 380 cc
Working fluid	Hydrogen
Engine efficiency	38–40%
Generator	
Type	Induction
Rotation speed	1800 rpm
Efficiency of generator	0.92–0.94
Solar Dish Stirling System Performances	
Electrical output at 1000 W/m ²	25 kWe
Peak net efficiency	29.4%
Max output power	27 kWe
Annual efficiency	24%
Minimum insolation	250–300 W/m ²

transfer methods are commonly used in the parabolic dish receivers:

- Direct-illumination receivers (DIR): Adapt the heater tubes of the Stirling engine to absorb the concentrated solar flux. It's capable to absorb high levels of solar flux. This type of receiver is used in several Dish Stirling systems like EURODISH, Suncatcher and Sundish.
- Indirect receiver (Liquid-metal, heat-pipe solar receivers): Uses a liquid-metal intermediate heat-transfer fluid, the liquid sodium metal is vaporized on the absorber surface of the receiver and condensed on the Stirling engine's heater tubes, that's assures a uniform temperature on the heater tubes.

Table 3 – Design characteristics of the proposed CSTPP.

Characteristic	Value
Total solar field capacity	100 MW
Number of collector	4000
Number of collector North-South	50
Number of collector East-West	80
Dish Collector Separation North-South	15 m
Dish Collector Separation North-South	15 m
Total solar field area (land use)	900000 m ²

**Fig. 3 – Solar map assessment in Algeria with direct Normal irradiation.**

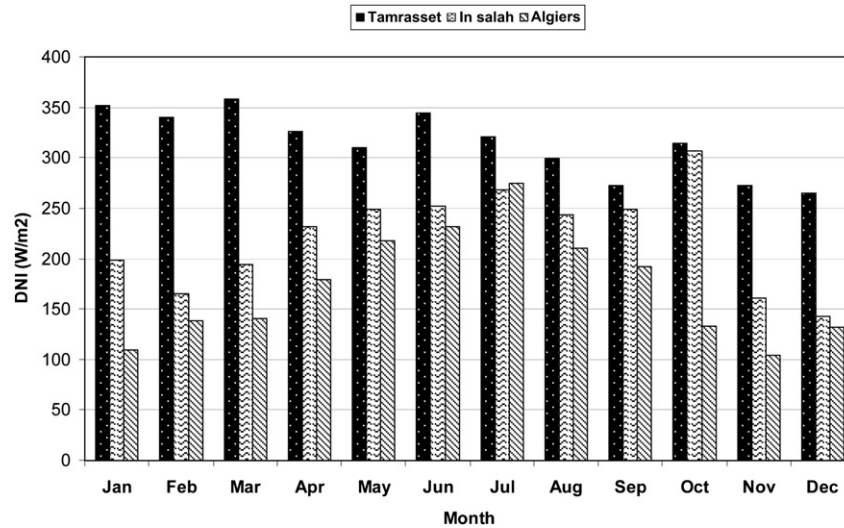


Fig. 4 – average Direct Normal radiation per month at three sites chosen.

3. Algeria topography and its solar potential

To determine the potential use of solar Dish Stirling technology for electricity generation in Algeria, it's indispensable to take a look at its geographical and climatic conditions. The geographic location of Algeria, in the Sun Belt region, has several advantages for the extensive use of the solar energy. Algeria is situated in the center of North Africa between the 38–35° of latitude north and 8–128° longitude east, it has an area of 2,381,741 km². The Sahara represents 86% of the area of the country. The climate is transitional between maritime (north) and semi-arid to arid (middle and south).

According to a study of the German Aerospace Agency (DLR) based on satellite imaging, Algeria has with 1,787,000 km² the largest long term land potential for the CSTPP. In addition, as shown in Table 1[2], solar radiation fall between 4.66 kWh/m² and 7.26 kWh/m², this corresponds to 1700 kWh/m²/yr in the north and 2650 kWh/m²/yr in the south, it is considered as being one of the best insolated areas in the world. The average solar duration over the quasi-totality of the national territory exceeds 2000 h annually and may reach 3900 h in the Sahara.

The total energy received is estimated at 169,400 TWh/year [28]. However, the technical and economical potential for electricity generation by CSTPP in Algeria is about 170000 TWh [29].

The solar map of Algeria has been elaborated and witnesses to the high solar potential of the country, as shown in Fig. 3[30]. It's worth to note from this figure that all the south of Algeria is a suitable for the implementation of CSTPP.

4. Simulation study

4.1. Characteristics of Dish Stirling power plant proposed

Because the Dish Stirling systems are modular; each system is a self-contained power generator, they can be assembled into plants ranging in size from a kilowatts to 10 MW. They are well suited for centralized and decentralized power production. In the centralized electricity generation option, the solar dish Stirling systems are believed to be the most viable solution for the future and provide the highest efficiency of all. The dish Stirling power plant simulated in the present investigation has

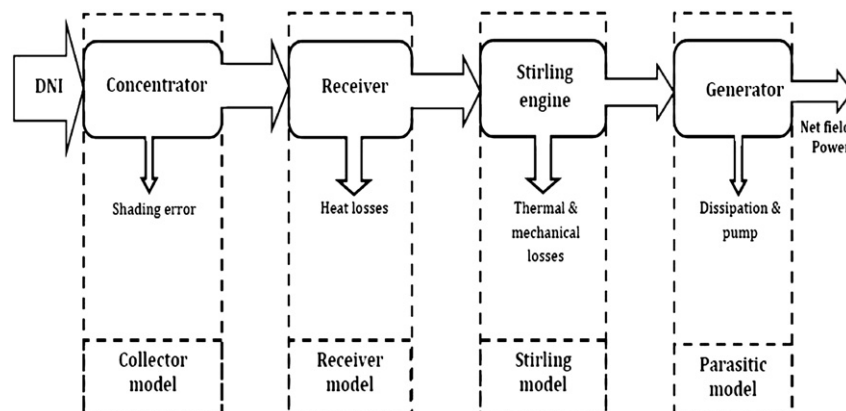


Fig. 5 – Model methodology.

an output of 100 MW, based on Dish Stirling System of 25 kW_e for each module intended for centralized electricity generation, whose baseline parameters are given in Table 2[13] and Table 3. The area required for the plant is 900000 m². The number of collector required is 4000, divided into 50 collectors of 91.1 m² each in the North-South direction and 80 in East-West direction.

4.2. Sites selection for installing the proposed plant

The climatic conditions are a decisive parameter to determine the suitability of such site for the implementation of CSTPP technologies that does not appear to be economical on sites with DNI below 1800 kWh/m²/year [31]. Moreover, three representative sites covering all climatic zones of Algeria were chosen to test the 100 MW Dish Stirling plant proposed, as following:

- Algiers: located in the coaster region of Algeria (Latitude 36°0.45' N, longitude 3°0.00' E, altitude 116 and the sum of direct normal irradiation is 1489 kWh/m²/year). The overall mean temperature is about 16.8 °C. The overall mean value of wind speed is about 1.5 m/s.
- In Salah: located in middle of the Sahara (latitude 27°0.20' N, longitude 2°0.46' E, altitude 268 m and sum of direct normal irradiation is 2511 kWh/m²/year). The overall mean temperature is about 26 °C. The overall mean value of wind speed is about 3.1 m/s.
- Tamanrasset: located in the south extreme of Algeria (latitude 22°0.47' N, longitude 5°0.31' E, altitude 1377 and sum of direct normal irradiation is 2691 kWh/m²/year). The overall mean temperature is about 23 °C. The overall mean value of wind speed is about 3.2 m/s.

Furthermore, solar radiation data were regularly recorded over several years in the three sites chosen. The monthly average direct normal radiation data of these three sites chosen is plotted in Fig. 4. At Algiers, the irradiation level is high during the summer months and the peak is reached in July. At the others two sites (In Salah and Tamanrasset) the irradiation level is high over the year.

4.3. Estimation of the plant's energy output

The simulation of the energy output of the Dish Stirling plant at three sites suggested is performed using the SAM software in which the global model is composed of four submodels, each of them representing a stage of the conversion cascade, solar-electricity, as shown in Fig. 5. The calculation conducts in the following manner:

- Calculation of the total power collected and delivered by the collector (Collector Power In, Collector Power Out), each of following parameters must be used:
 - Hourly Direct Normal Irradiation (DNI) of the three sites
 - Ambient temperature, atmospheric pressure and wind speed
 - Sun angle and solar azimuth degree
 - Concentrator size (area, focal length) and its intercepted factor

Table 4 – Assumptions and data.

Assumptions and data	Value
Life time	30
Electricity sale price (\$/kWh)	0.13
Discount rate (%)	8
Annual electricity generated (MWh)	130541
Direct costs	
Collector cost (\$/m ²)	400
Receiver cost (\$/kW)	250
Stirling engine cost (\$/kW)	500
Contingency (% of direct costs)	10
Indirect costs	
Engineering, Procurement and Construction (% of direct costs)	16
Other costs (% of direct costs)	3
Land purchase (\$/m ²)	0
Total installed cost per capacity (\$/kW)	2965.39
Operation and Maintenance costs	
Fixed (\$/kW-year)	50
Variable (\$/MWh)	7

- Number of dishes
- Dishes separation North-South and East-West
- Collector array shading
- Calculation of the power delivered by the receiver (Receiver Power Out) using the following parameters:
 - Receiver dimensions such as the aperture diameter, absorber surface area, cavity wall surface area
 - Absorptance and insulation thickness and conductivity
 - Temperature of heater head
- Calculation of the power delivered by the Stirling engine to the generator (Gross Field Power) using:
 - Beale constant coefficient
 - Engine speed
 - Volume displaced of the engine
- Calculation of the net electric power output (Net Output) after subtraction of parasitic electric power via the use of pump and fan parameters.

Each stage of the plant performances calculation requires some parameters. The details of these calculations as various mathematical equations can be found in Ref. [32].

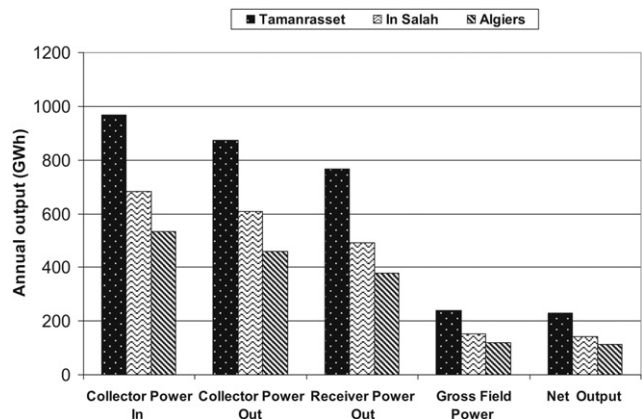


Fig. 6 – Dish Stirling plant waterfall chart at three locations.

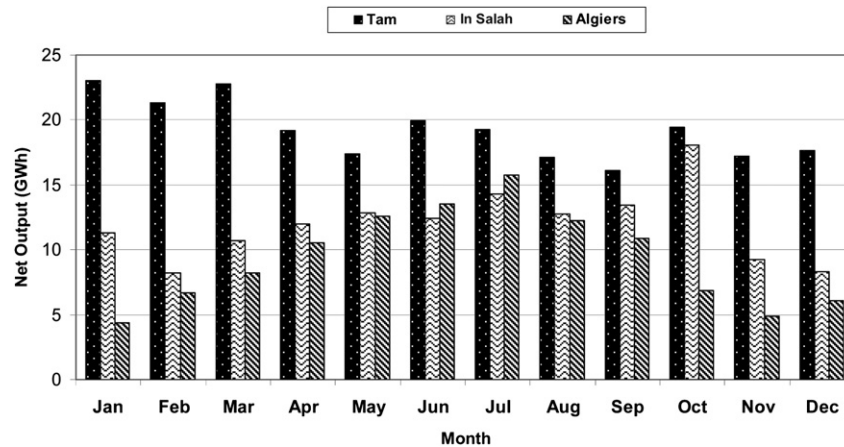


Fig. 7 – Power output at three locations versus months of a year.

In Algeria, the climatic conditions are measured by the Office National de Météorologie (i.e ONM) via 54 stations spread over the whole territory. In regard to the meteorological data of Tamanrasset for example, the global, diffuse and direct radiation are recorded since September 1994 by the station working with solar energy implanted at Tamanrasset city center [33]. In this study, a typical meteorological year (TMY) data set of sites considered has been used, which contains hourly values for the DNI, ambient temperature, wind speed, sun angle, atmospheric pressure and solar azimuth angle for one complete year.

4.4. Economic feasibility study

The economical considerations of utilizing the solar energy for electric generation are the most important aspect in the selecting of the proper technology to be used in any project and location. If appropriate location is chosen, solar thermal power plants will be economically viable option for the production of electricity [34]. To study the economic feasibility of a solar power system, different methods could be used to evaluate different figures of merit of the systems. Each method has its own advantages, disadvantages, limitations and some conditions to be satisfied so that it can be applied [35]. In this study, the calculation of both real and nominal Levelized Cost of

Energy (LCOE) was performed, using the annual project cost incorporating both direct (collector, receiver and Stirling engine costs) and indirect cost (Engineering, Procurement and Construction costs). For an analysis from the point of view of a public service, calculation is simplified by omitting the different taxes (insurance...) and the land is offered by the Algerian state. The details of equations used for calculating the LCOE can be found in Ref. [36]. The economical assumptions and data made for making simulations on SAM software are presented in Table 4.

5. Results and discussions

The plant waterfall chart from solar energy to net power output which shows the performance of each system component as power flows through the system [13] is shown in Fig. 6. Each three vertical bars show a step of conversion while showing the optic, thermal and electric losses in the Dish Stirling system. The first 3 bar show the amount of solar radiation collected by the concentrators in three sites proposed. Each other consecutive 3 bar show losses associated with the following sequential transfers of solar energy and heat into electrical power, such as shading errors in the concentrators, heat losses in the receivers, thermal and mechanical losses in Stirling engine

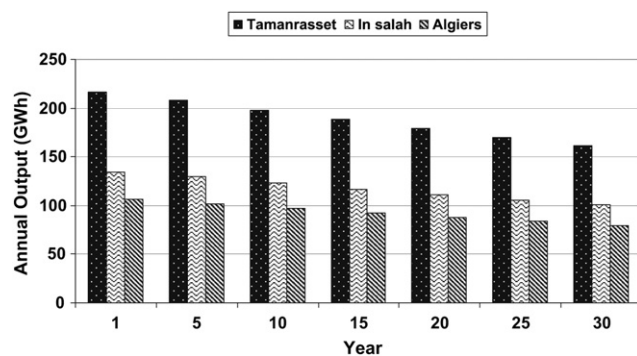


Fig. 8 – Power output at three locations versus years of working.

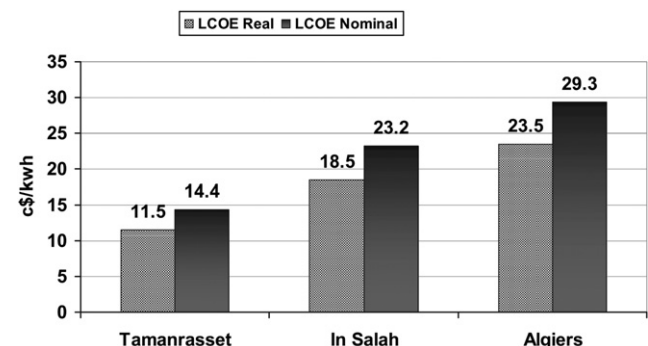


Fig. 9 – LCOE for the plant proposed in the three sites.

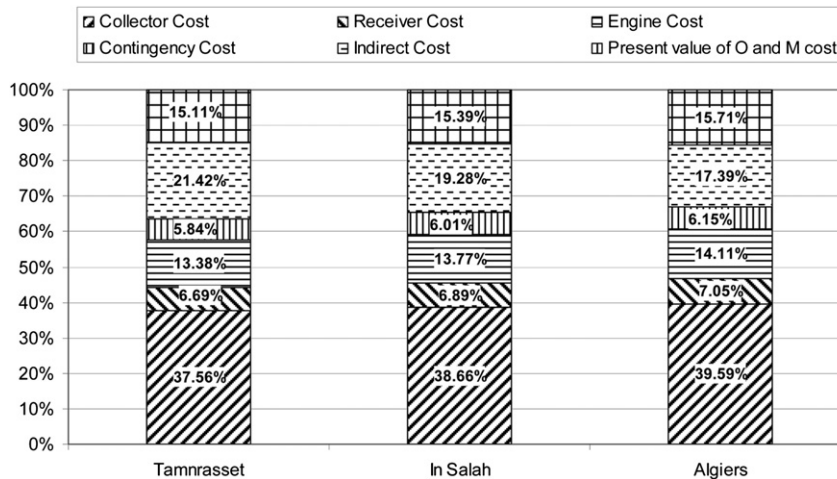


Fig. 10 – The relative contribution of each project cost.

and last the parasitic power which is required to operates pumps and fun of the plant.

From this figure, the calculations indicate that the efficiency of solar- net electric conversion is 24%, 22% and 21% in Tamanrasset, In Salah and Algiers respectively.

To study the monthly evolution, the variation of the monthly net field power production of the Dish Stirling plant proposed is shown in Fig. 7 for the three sites chosen. It can be seen also that the monthly production in Tamanrasset is very important, while Algiers present the lower monthly production. The results show that the high power values are reached over the year in Tamanrasset and In Salah and between Mars and October in Algiers. The peak power reaches 23 GWh in Mars, 18 GWh in October and 15.7 GWh in July respectively. The lowest value of 16.1 GWh in September of this year for Tamnasset is even higher than the peak of 15.7 GWh for Algiers.

The most important remark is that the monthly power production has a tendency to increase if we go from the coaster region to the south (Sahara) of Algeria.

In order to determine the degradation system, an analysis of the annual net electricity plant production over 30 years of operation has been carried out, as shown in Fig. 8. The net output in the first year of functioning is 216 GWh, 134.6 GWh and 106 GWh, while the output in the last year of working is about 161 GWh, 100 GWh and 79 GWh in Tamanrasset, In Salah and Algiers respectively. The system degradation calculated from the first year output is about 1%.

It can clearly be seen the difference between the annual production which is very important between Tamanrasset and the others sites. The annual net field power in Tamnasset is about 2.2 times than that produced in Algiers and 1.6 times than that of In Salah.

Fig. 9 illustrates both the real and nominal Levelized Cost of Energy (LCOE) of the Dish Stirling power plant at different three locations. The simulation results indicate that Tamanrasset is the best site yielding the lower LCOE. The real LCOE is found to vary between 11.5 c\$/kWh at Tamanrasset, 18.5 c\$/kWh at In Salah and 23.5 c\$/kWh at Algiers, while the nominal LCOE can reach 14.41, 23.19 and 29.33 c\$/kWh in Tamanrasset, In Salah and Algiers, respectively.

In order to determine the dominant cost fraction of the whole plant, Fig. 10 exhibits the relative contribution of each project cost. From this figure, one can see that the project cost is as a majority made up of collector cost, the engine, O&M cost and indirect cost also being big contributors.

6. Conclusions and outlook

Solar energy is the most abundant natural resource in Algeria, for that, it has to exploit it through different plans. The CSTPP represent the effective form of using solar energy for electricity production. In the last years, the Dish Stirling technology has proved the technical feasibility and economical viability through a number of projects lunched worldwide.

In this study, the SAM software is used to perform a techno economic investigation of 100 MW CSTPP based on Dish Stirling technology. The simulation has been applied in three locations where solar resources are variable, available and yielding to compare the CSTPP performances. The following conclusions can be drawn from the analyses:

- (1) The net electric power output of the plant proposed is proportional to the Direct Normal Irradiation which is maximal in the south regions, the significant values are detected in In Salah and Tamanrasset. It appears that the technical performances of the Dish Stirling plant proposed has a tendency to increase (and the economical performances to decrease) if we move from the coaster regions (north) to the Sahara region (south) of Algeria.
- (2) The LCOE varies in the range of 11.55 and 23.55 c\$/kWh depending on the site chosen. These values are lower than those of ECOSTAR study [37] and comparable to those of [38].
- (3) In the Sahara which represents 86% of the total surface of Algeria, there is an important solar radiation potential and very vast abundant land. The Sahara, Tamanrasset in particular, is therefore suitable for construction sites of CSTPP for centralized electricity generation. This confirms some studies [10,17,39–41] which have shown the

importance of Tamanrasset as one of the favorable sites for solar electricity and hydrogen production.

- (4) There is no doubt that the introduction of this technology would bring Algeria many advantages, such as:
 - Create more new jobs
 - Improve lifestyle of the population living in the isolated and desert area of Algeria
 - Preserve the energy fossil resources
 - Develop the metallurgic industrial sector which presents the necessary assets for the locally design and construction of some components.
 - Protect the environment and promote even more investment in solar energy sector.
- (5) The CSTPP are needed to meet the growing electricity demand and substitute the damaging emissions of conventional sources together with other renewable energy resources.

Finally, it's obvious that a series of sensitivity study is indispensable in order to determine the conditions which make this technology profitable and economically feasible.

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